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A numerical study of the aerodynamic admittance of bridge deck sections by a two-dimensional mesh-free vortex method

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ABSTRACT

Since the original Tacoma Narrows bridge collapsed in 1940 the study of bridge aerodynamics has been subject to intense research, and many resources are normally used in conducting extensive wind tunnel tests in order to prevent a similar failure. The main parameters when analysing the aerodynamics of a bridge are the influence of static, periodic and random forces acting on the bridge i.e. the effect of steady wind, vortex shedding and turbulence in the oncoming wind.

The aerodynamic admittance function relates the turbulent oncoming wind and the resulting buffeting aerodynamic forces experienced by the bridge section. It has been well established that the aerodynamic admittance function vary significantly between different bridge designs, and the thin airfoil theory is insufficient due to non-negligible flow separation which is characteristic in bluff body aerodynamics.

The mesh-free vortex method is widely used in academia and industry to model two-dimensional flow around bluff bodies. The two-dimensional implementation DVMFLOW [1] is used by the bridge design company COWI to determine steady flow parameters and visualise the flow field around bridge sections. Recent work [2] includes an implementation of an oncoming turbulent flow into DVMFLOW, together with an extensive spectral analysis, resulting in an improved numerical tool for analysing the effect of oncoming turbulence on the aerodynamic behaviour of bluff bodies.

The turbulent oncoming flow is implemented by seeding an array of vortex particles upstream of the bridge section. The vorticity of the particles is calculated a priori using the statistical method proposed by Di Paola [3]. First, a turbulent velocity field is generated by Fourier transforms of correlated velocity spectra constructed from a design velocity spectra and the coherence function of Batchelor [5] for the spatial correlations of homogeneous turbulence. By using the analogy of the temporal and spatial correlation functions of turbulence, the spatial representation of the velocity field is considered as a discrete time progressing vector field of a one cell array. The vorticity of a cell centred particle is then found for each time step by integrating the velocity of the surrounding cell points.

A validation of the method was performed by simulating the turbulent flow past a flat plate. The resulting aerodynamic admittance function (not shown) was found to agree well with thin airfoil theory represented by Liepmann's approximation of the Sears function [6].

The method was applied to a number of different bridge sections and a general good agreement was found to experimental results. The simulated aerodynamic admittance of the Øresund bridge are shown

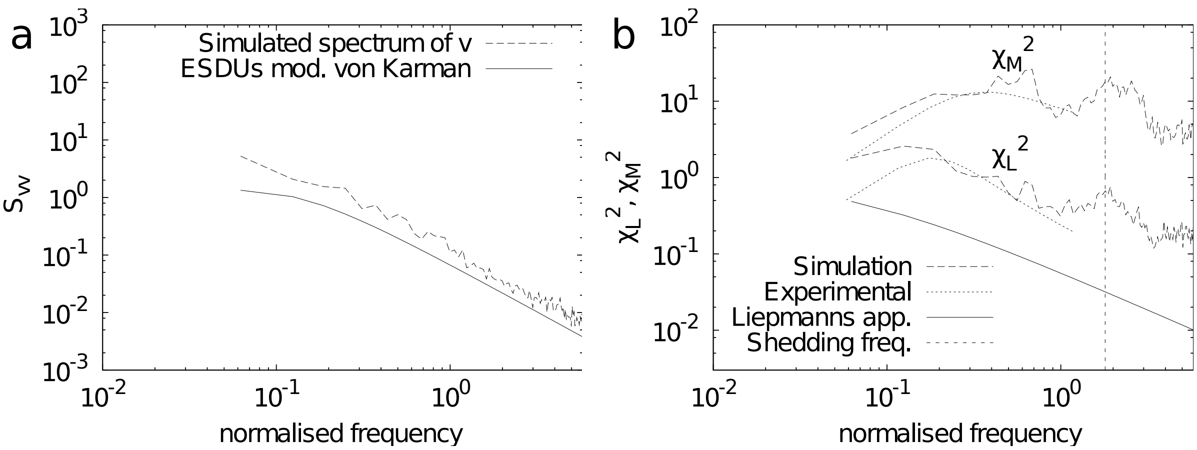

Figure 1: (a) The simulated velocity spectrum of the vertical component S_{vv} compared to the design spectrum of ESDU [4]. (b) The calculated aerodynamic admittance functions for lift χ_L and pitching moment χ_M compared to experimental results and the Liepmann approximation [6].

in Figure 1b. It is seen that the aerodynamic admittance functions obtained by the simulation agrees well to the experimental data however deviates significantly from Liepmann approximation.

The simulation provides results over a far wider frequency range than possible in wind tunnel tests, which suffers from practical restrictions. The wider frequency range reveals more information about aerodynamic characteristics of the section and enables an estimation of the vortex shedding frequency given by the peak value in Figure 1b. Furthermore, the method can be used to study the flow at different intensities of the upstream turbulence and thereby investigate the effect that turbulence has on other aerodynamic parameters, such as vortex shedding and the aerodynamic stability of the bridge section.

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